Session 504: Intro to Marine Composites Design-Advanced Methods

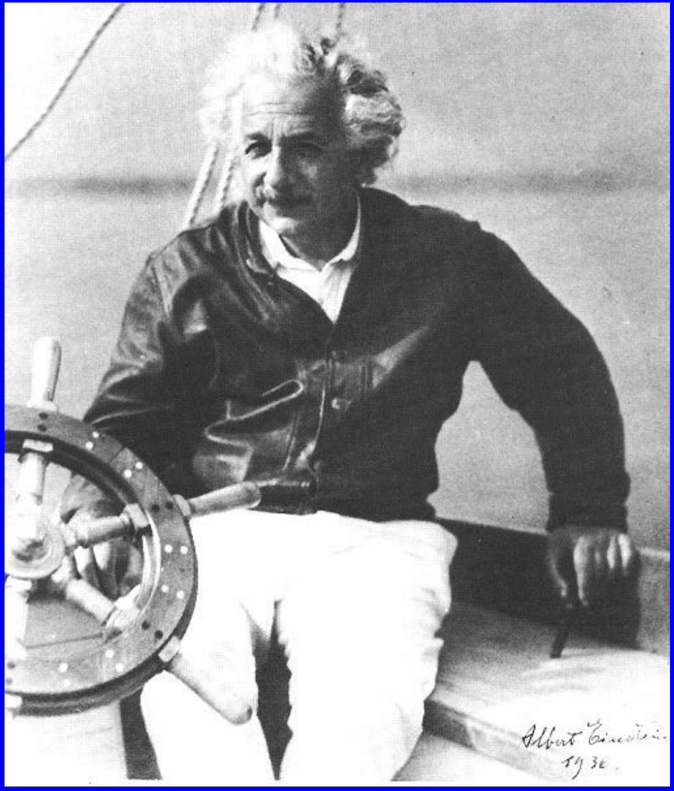
Dr. Paul H. Miller, PE

U. S. Naval Academy

Intro to the Advanced!

- Goals:
  - Advanced methods for marine composites design (Session 404 was basic methods)
  - Some “lessons learned the hard way” (also called “case studies”)
  - Some entertainment value!

If this is not you, don’t worry!



My assumptions!

- You have some background in composites fabrication and design
  - You know what the common fibers and resins are (E-glass, epoxy, etc.)
  - You know the basic English units of length, force, area, time
  - You have used “scantling rules” such as ABS, ISO, Herreshoff, etc.!
  - You have designed using metal.

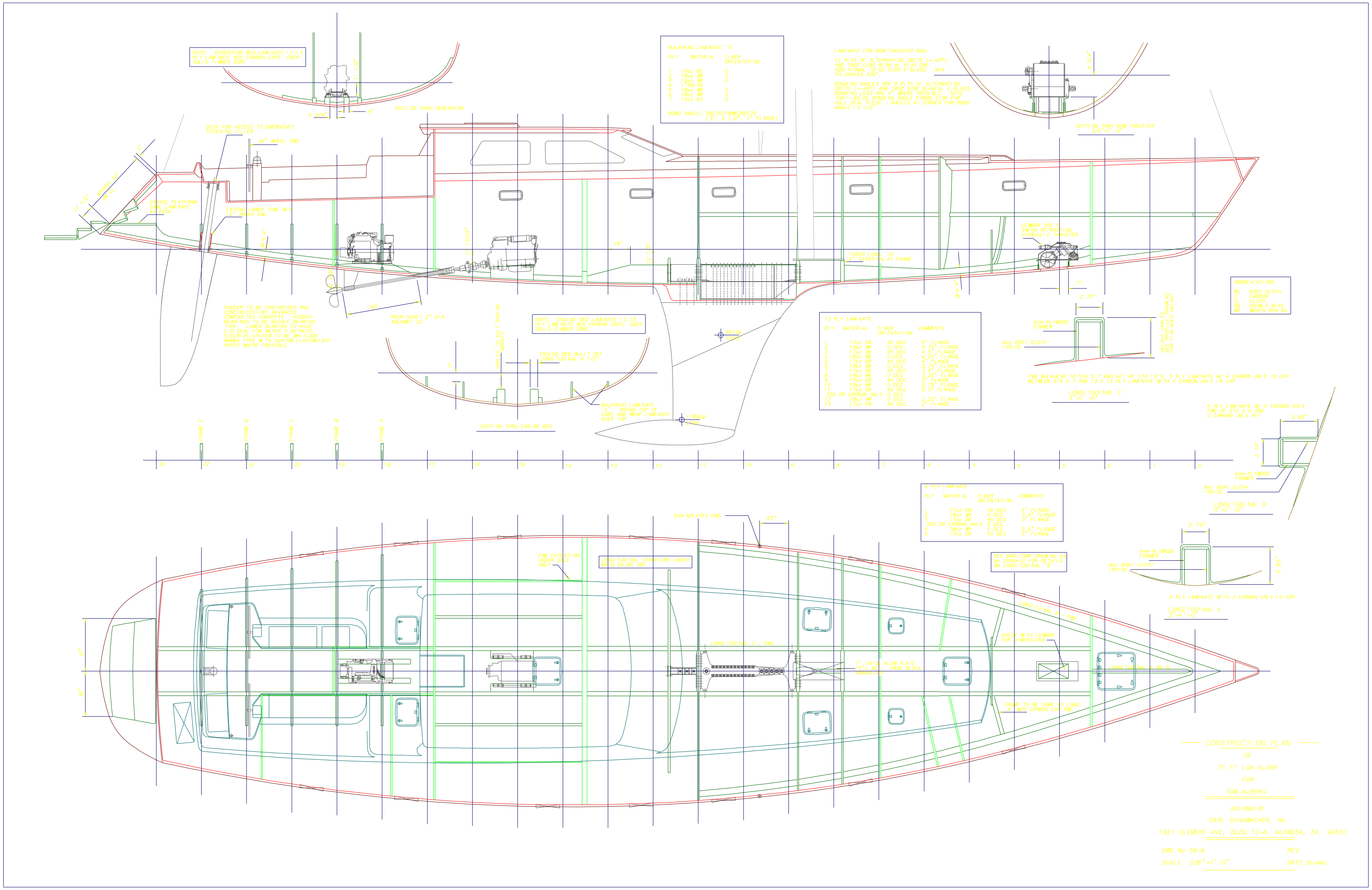
What is “design”?

- The purposeful arrangement of parts
- To create in a highly skilled manner
- A drawing or sketch

What is “Marine Composites Design”?

- Intelligent selection and combination of materials (resins, fibers, cores) to create a structure that fulfills a customer’s requirements
- Communicating that information!

Drawing



CONSTRUCTION PLAN
OF
77 FT LOA SLOOP
FOR
TOM ALBERG
DESIGNED BY
CARL SCHUMACHER, NA
1921 CLEMENT AVE, BLDG 13-A, ALAMEDA, CA 94501
DWG No 58-6
REV
SCALE 3/8"=1'-0"
DATE 30JAN01

Or Simple Laminate Table

Transom Ring Frame			
Ply	Material	Fiber Orientation	Comments
1	12 C DB	45	4" flange
	300 g C uni's	0	5 cap plies (dk beam only)
2	12 C DB	0	3.75" flange
	300 g C uni's	0	5 cap plies (dk beam and frame)
3	12 C DB	45	3.5" flange
	300 g C uni's	0	5 cap plies (dk beam and frame)
4	12 C DB	0	3.25" flange
	300 g C uni's	0	5 cap plies (dk beam only)
5	12 C DB	45	3" flange
Notes:	1" fillet radius to hull		
	fabricated over 6 lb foam		

This Seminar's Focus

- Demonstrating advanced analysis methods
- Some information on selecting materials

General Design Approaches

- Numerical methods (number crunching)
- Experimentation (prototypes)
- Empirical development (small changes each time)
- Plagiarism! (Not recommended if you are in college) Also called, “benchmarking”.

Numerical Structural Design Requires:

1. Geometry (what will the part look like, dimensions of length, width, maybe thickness)
2. Loads
3. Material properties, and
4. An analysis method (what theory to use)

The Most Fun Part is:

- Figuring out what it will look like!
  - In general, smaller parts require less structure, but also require more tooling costs and labor costs
  - Joints are expensive!
  - Aim for few parts

The Hardest Part is:

- What are the loads?
- Brainstorm on all the reasonable ways your customers can abuse your product!
- Did you think about high heels?

Easier Methods from Session 404

- Combined methods (loads and analysis). Often called “Scantling Rules”
- American Bureau of Shipping (ABS)
- Lloyds, DnV, ISO, etc.
- Gerr’s Elements of Boat Strength
- Herreshoff’s, etc.

Advanced Methods in this Seminar

- Loads calculated independently from structural theory
- CFD, LPT, CLT, FEA, TLA, etc.
- Potentially more accurate, so potentially lighter and less expensive –break even point?

Material Properties

- For preliminary analysis only you can get properties from Greene or Scott.
- For detailed design it is usually not worth the effort of advanced analysis methods if you don't know the actual laminate properties

Scott Tables

Example Fig 11

- **For a 45% resin content, all woven laminate typical of very good hand layup, tensile strength is 36000 psi**

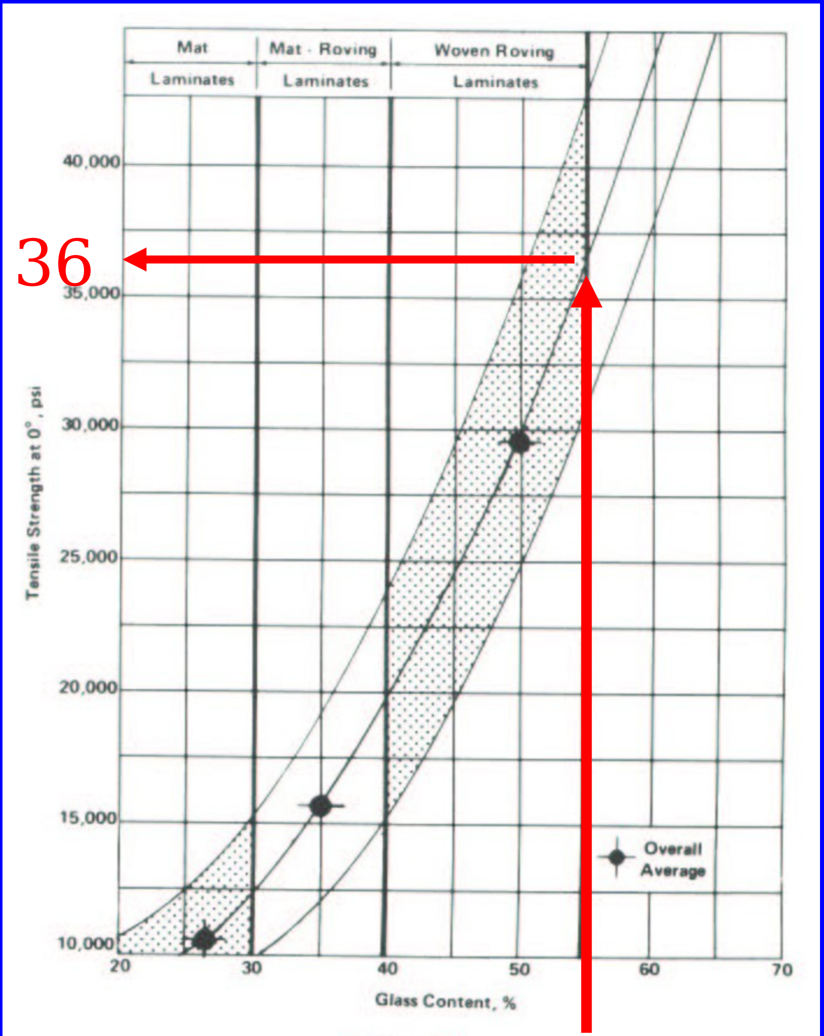
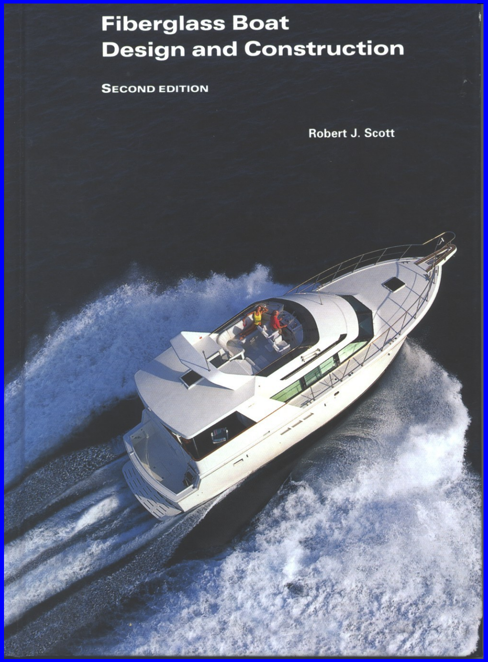


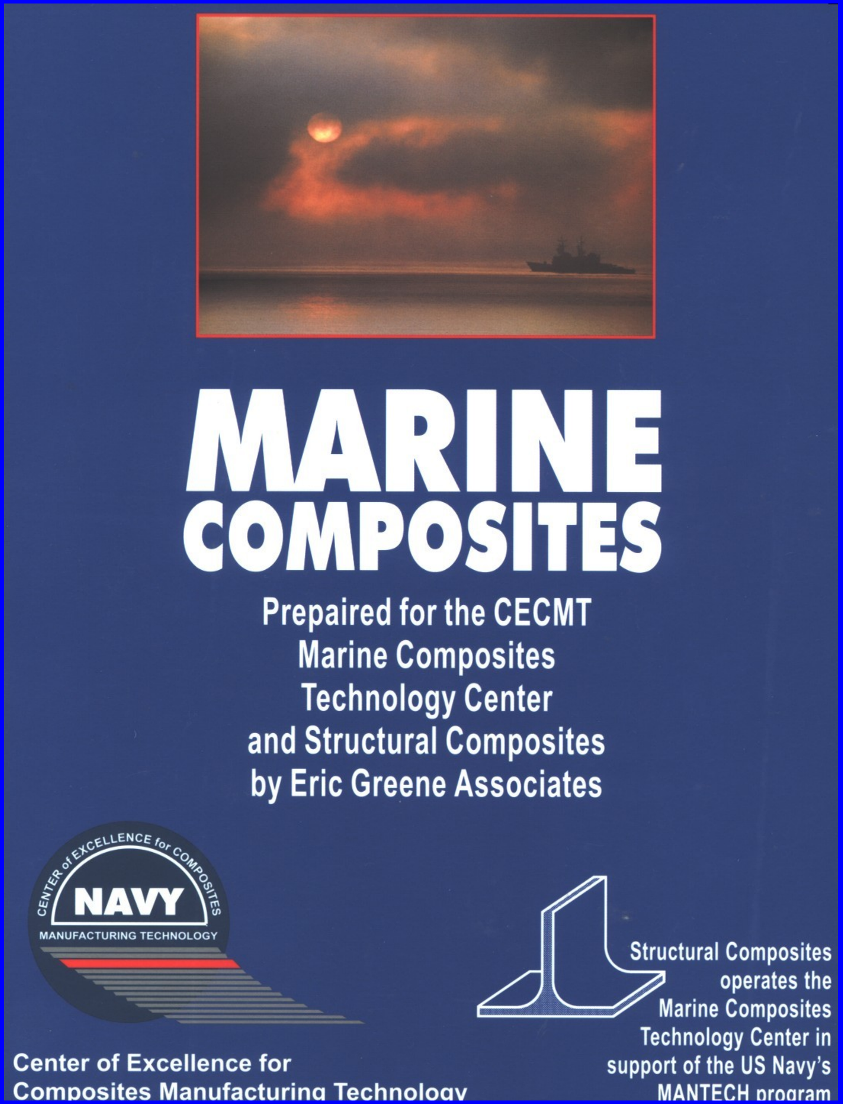
Figure 11
Tensile strength at 0 degrees (warp)



Only for typical mat, cloth and woven roving with polyester

Greene Tables

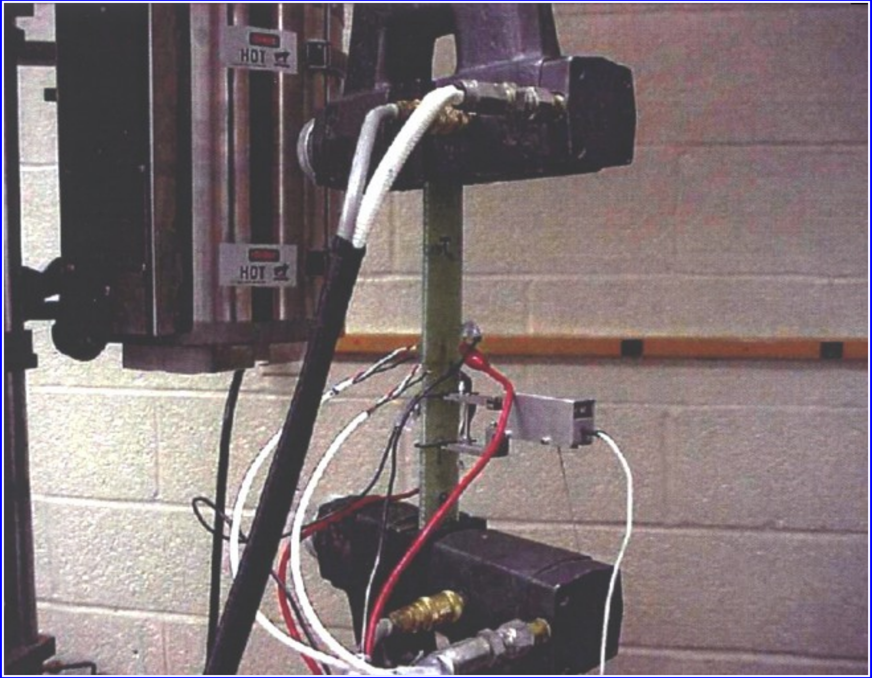
- Appendix A
- Example
  - SCRIMP 7781/epoxy
  - 34% resin content
  - Tensile strength is 56000 psi!



www.marinecomposites.c
Free download!

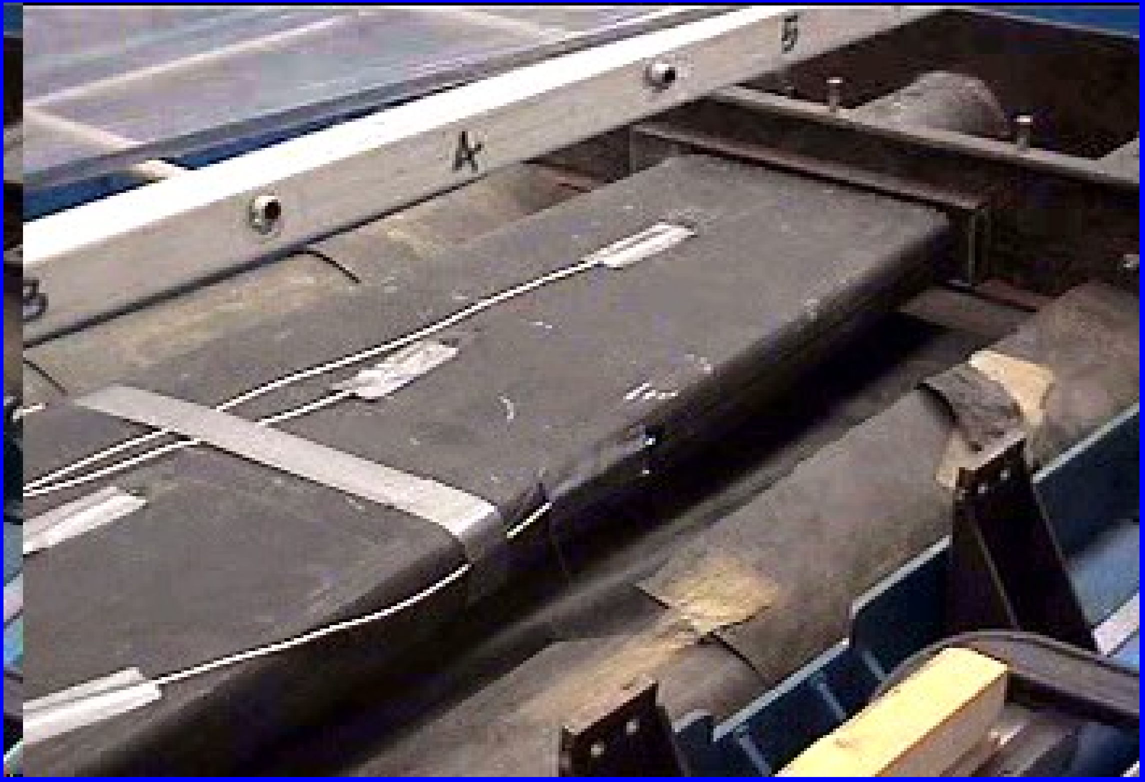
Testing Rules of Thumb

- **Choose tests most appropriate to your application.**
- **Greene has good summary of common tests**



ASTM D3039
Test for tensile
strength and

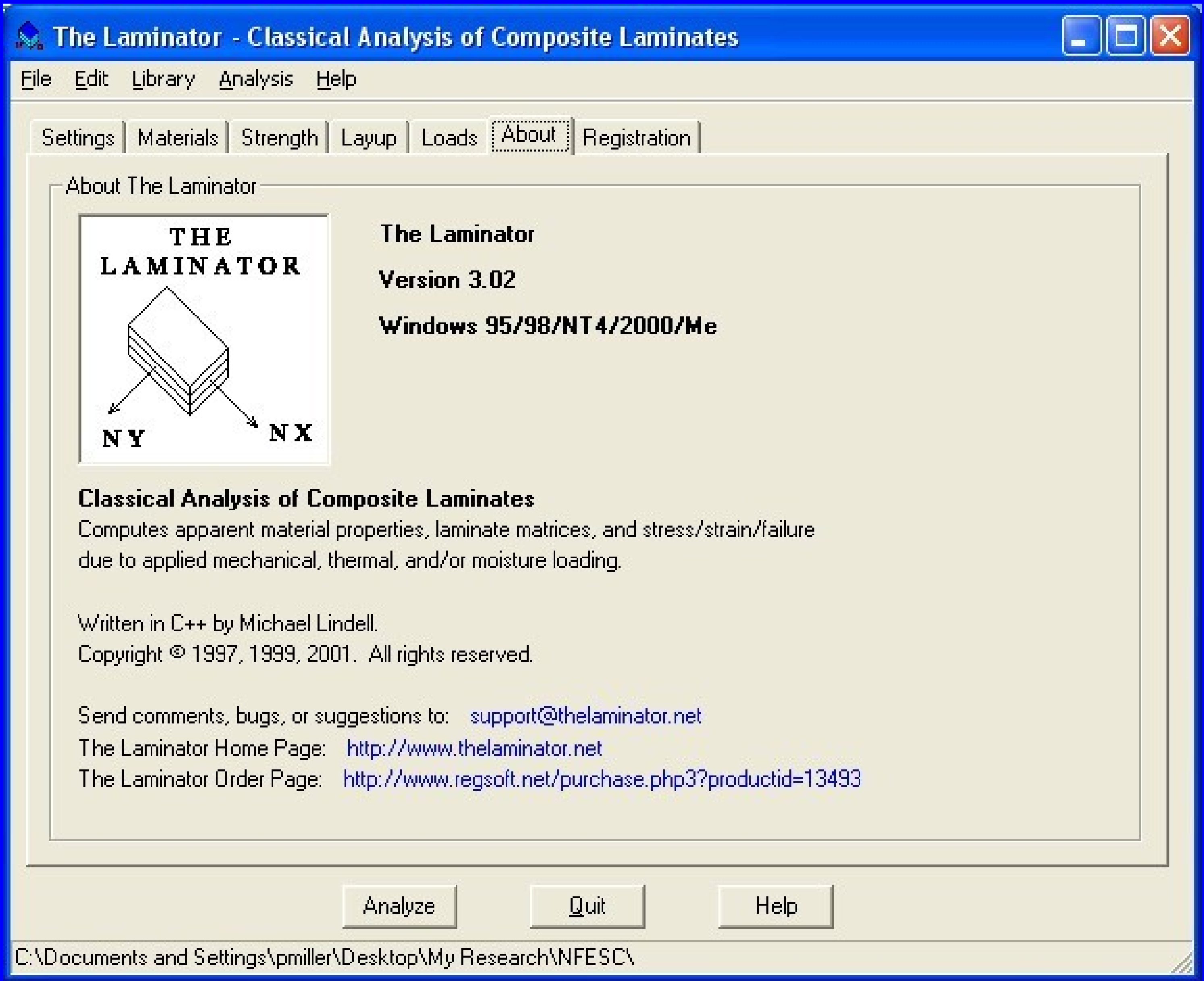
Panel Testing



Finding Laminate Properties Not in Scott

- Other than testing, the best method is Classical Lamination Theory (CLT). It is also called Laminate Plate Theory.
- It is nothing more than matrix math and can be done on a spreadsheet.
- Shareware programs are nice as they include features like material libraries

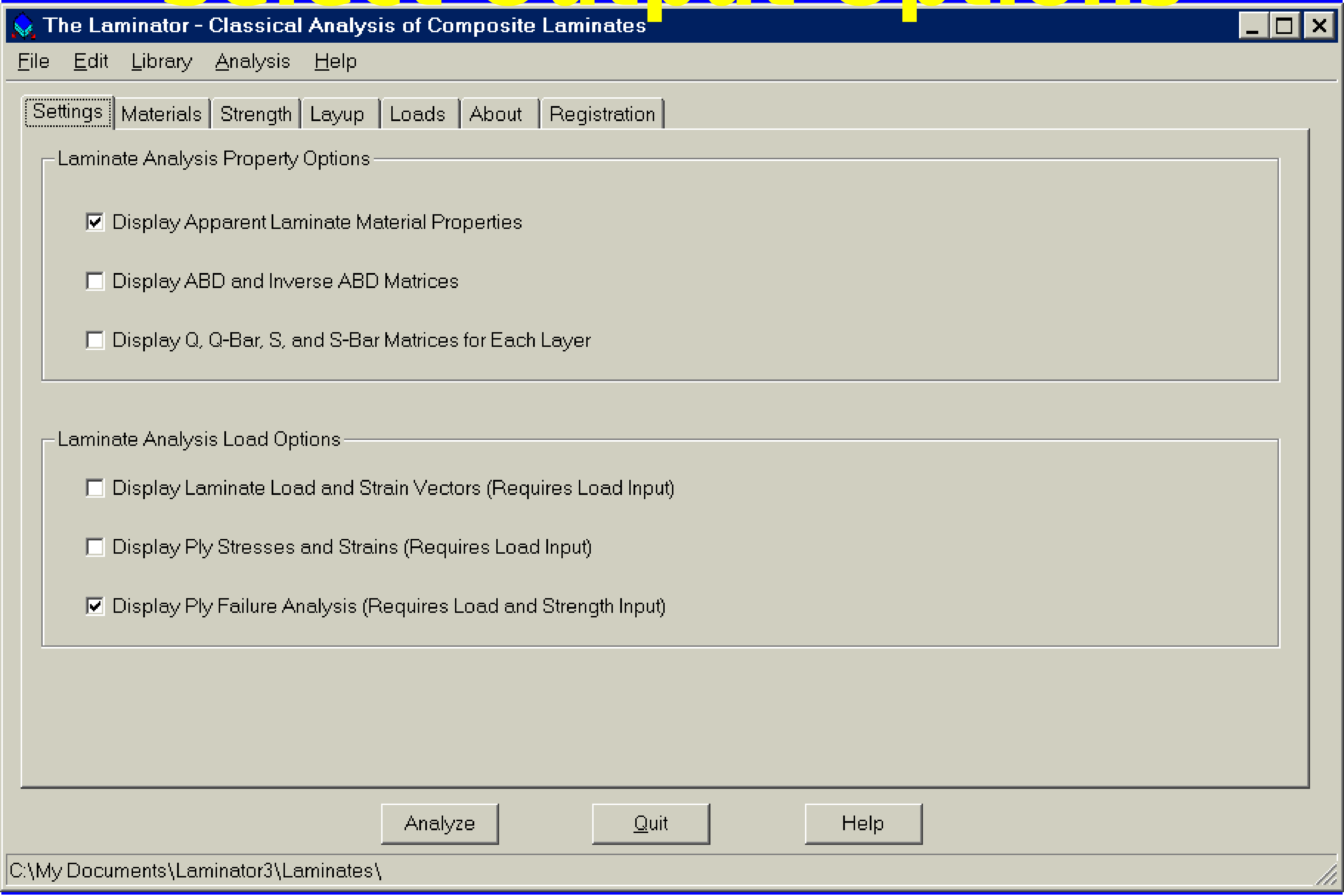
The $29 Laminator



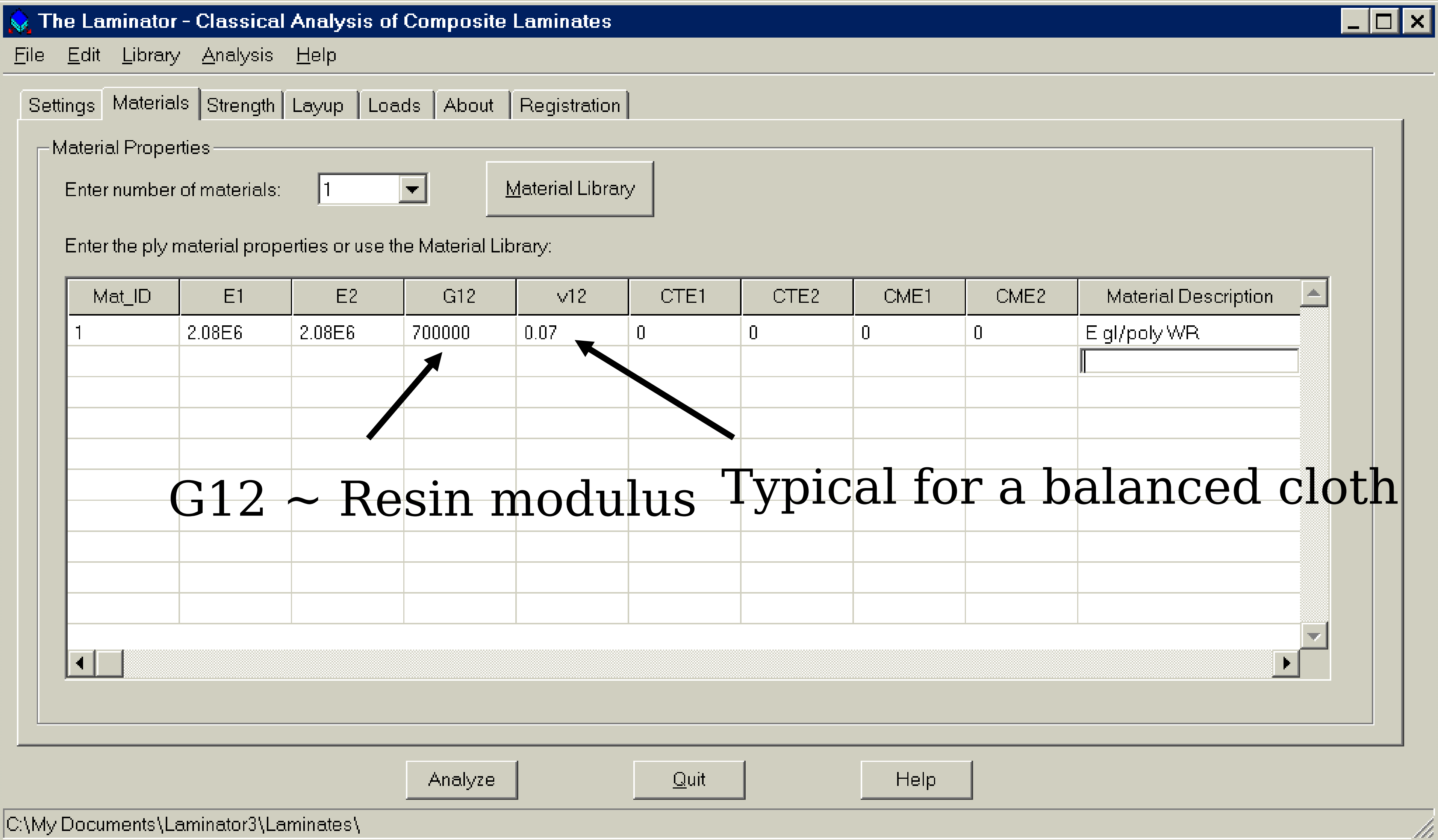
Example:

- We have a laminate that is three plies of 24 oz woven roving at 0/90, 0/90, 0/90, but it twists too much, so we want to know its properties if the middle ply is rotated 45 degrees
- Get 0/90 props from Scott
- Et=1.95 msi, Ec= 2.2 msi, ten str. = 29 ksi, comp str = 26 ksi, shear str. = 11 ksi, shear mod = ?, poisson’s = ?

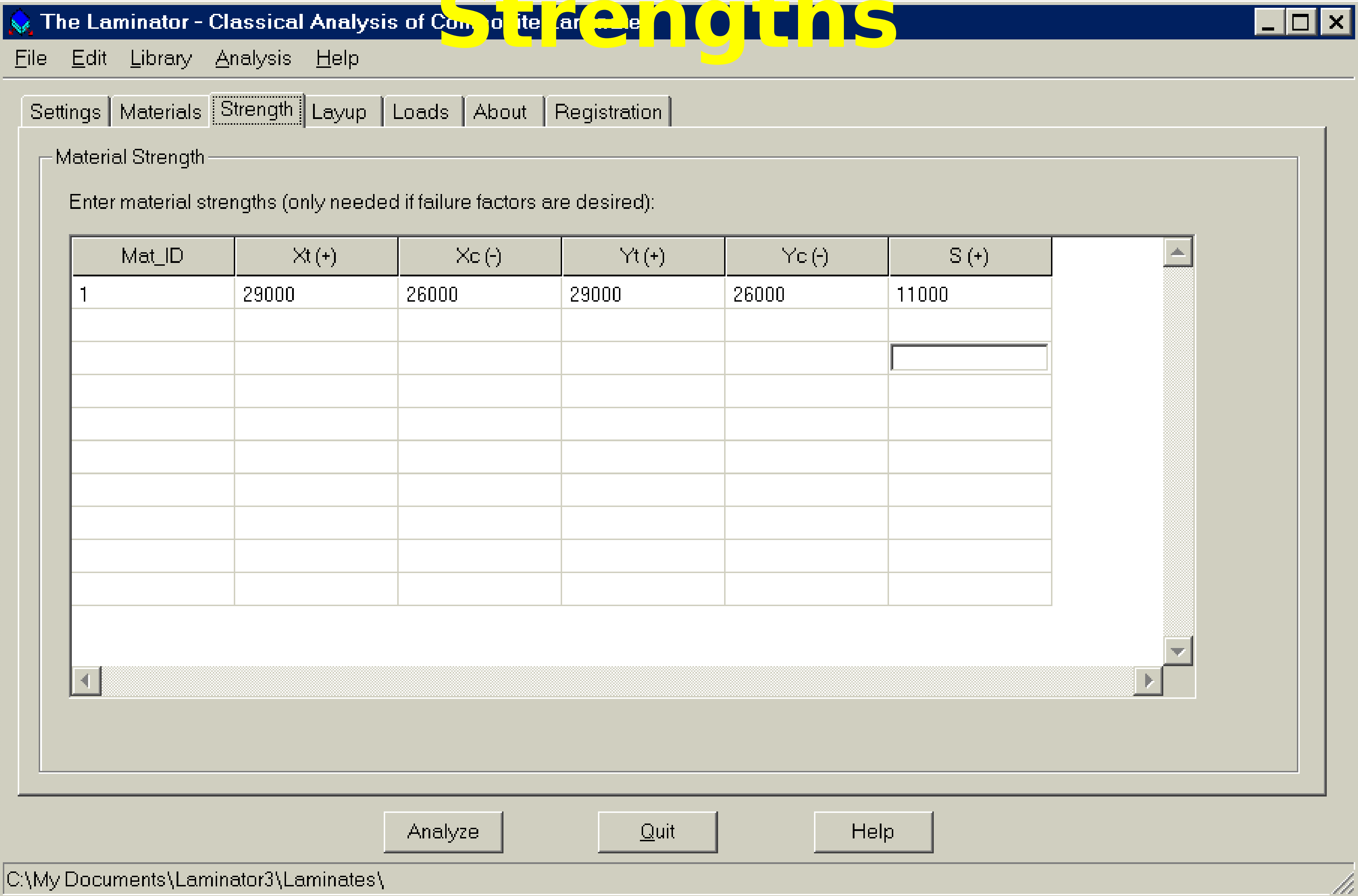
Select Output Options



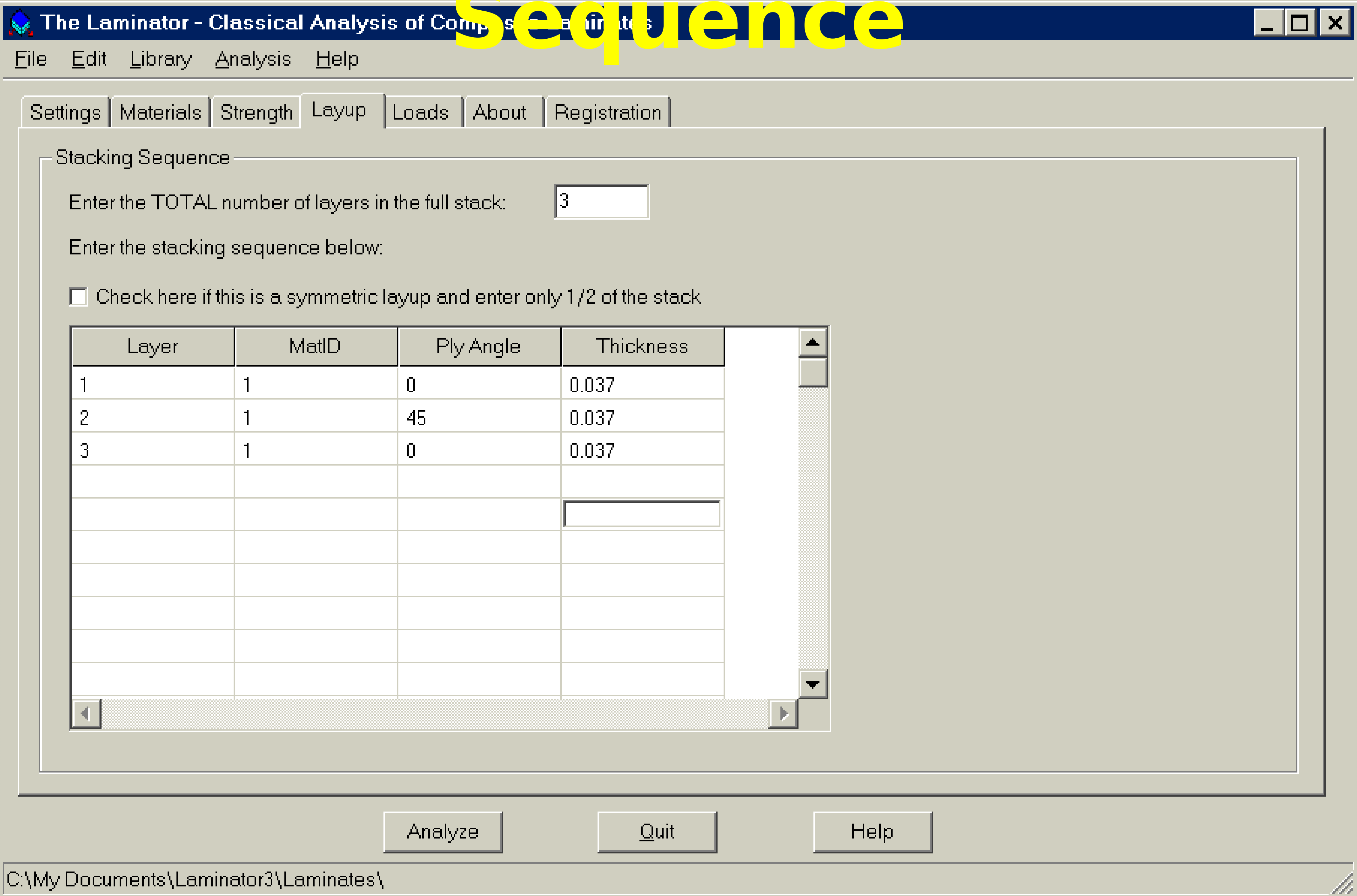
Define Material Stiffness



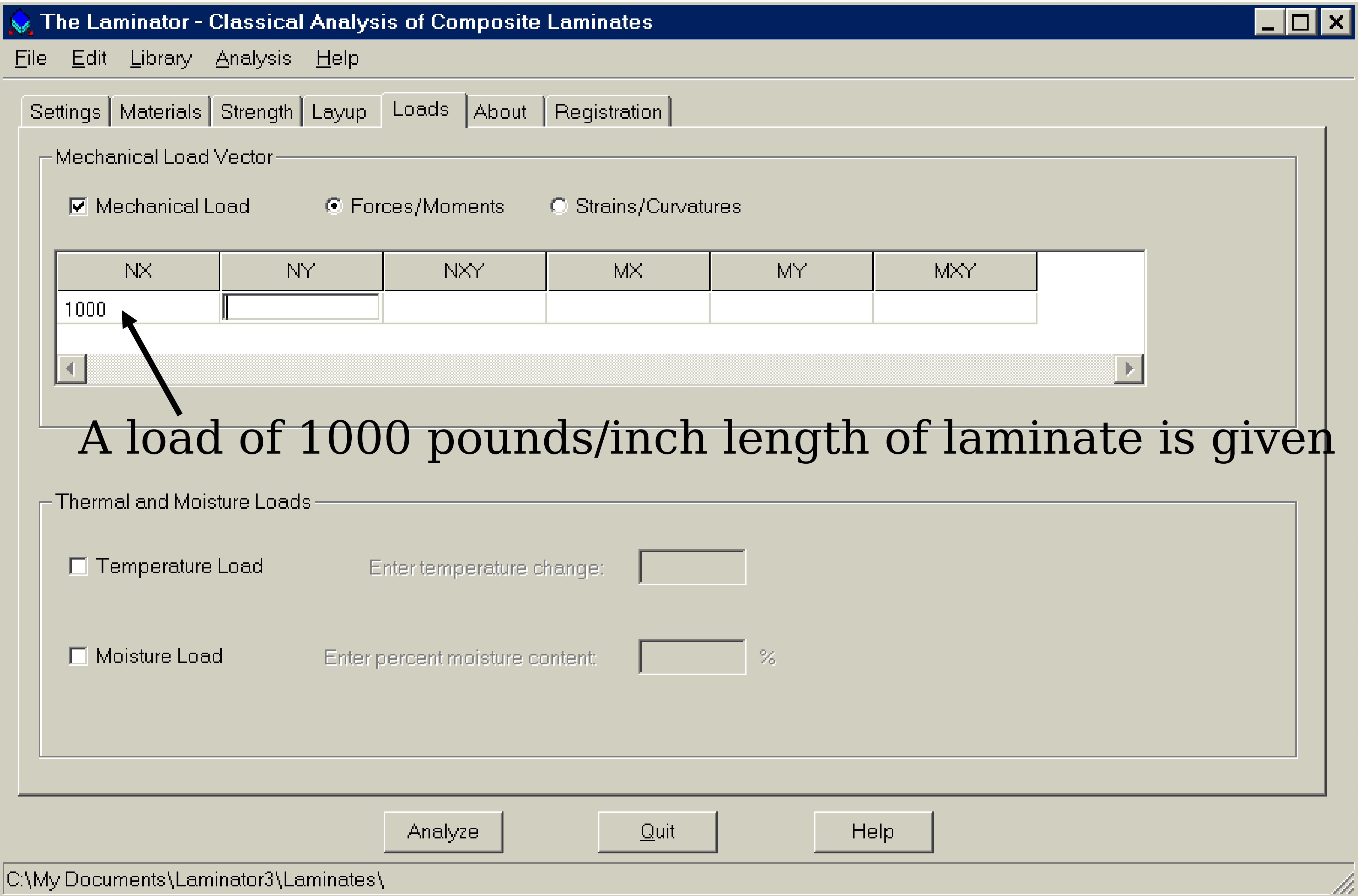
Define Material Strengths



Define Stacking Sequence



Define Loads



A load of 1000 pounds/inch length of laminate is given

Analysis Results

```
**************************************************************************
*                              The Laminator
*                 Analysis of Composite Laminates Based on
*                     Classical Laminated Plate Theory
**************************************************************************


Material 1: E gl/poly WR


Engineering Properties
**********************

Matl          E1            E2           G12         v12

  1       2.080e+006   2.080e+006   7.000e+005    0.070



Thermal and Moisture Properties
*******************************

Matl         CTE1          CTE2          CME1          CME2

  1       0.000e+000   0.000e+000   0.000e+000   0.000e+000
```

OK Print Save Help

C:\My Documents\Laminator3\Laminates\

Analysis Results

Stacking Sequence
****

Layer	Matl	Ply Angle	Ply Thickness
1	1	0.0	3.700e-002
2	1	45.0	3.700e-002
3	1	0.0	3.700e-002

Total Laminate Thickness :			1.110e-001

Laminate Mechanical Input Load Vector
****

NX	NY	NXY	MX	MY	MXY
1.000e+003	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000

Apparent Laminate Stiffness Properties
****

OK Print Save Help

C:\My Documents\Laminator3\Laminates\

Analysis Results

Apparent Laminate Stiffness Properties
****

EX	EY	GXY	EXB	EYB
1.972e+006	1.972e+006	7.907e+005	2.068e+006	2.068e+006

Apparent Laminate Coupling Coefficients
(Poisson and Shear Coupling)
****

vXY	vYX	nXY,X	nXY,Y	nX,XY	nY,XY
0.119	0.119	0.000	0.000	0.000	0.000

Apparent Laminate Thermal and Moisture Properties
****

CTEX	CTEY	CTEXY	CMEX	CMEY	CMEXY
0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000	0.000e+000

OK Print Save Help

C:\My Documents\Laminator3\Laminates\

Analysis Results

Material Strengths
****

Matl	Xt	Xc	Yt	Yc	S
1	29000.0	-26000.0	29000.0	-26000.0	11000.0

New tensile strength is: 2.88 x 1000 /0.111 =25,950 psi

Load Vector Scale Factors for Ply Failure
(For Applied (+) and Reversed (-) Loads)
****

Layer	Max Stress (+)	Max Stress (-)	Tsai Hill (+)	Tsai Hill (-)	Hoffman (+)	Hoffman (-)	Tsai-Wu (+)	Tsai-Wu (-)
1	3.06	-2.74	2.99	-2.68	2.97	-2.69	2.97	-2.69
2	3.07	-3.07	2.77	-2.71	2.88	-2.61	2.88	-2.61
3	3.06	-2.74	2.99	-2.68	2.97	-2.69	2.97	-2.69
---	------	------	------	------	------	------	------	------
Min	3.06	-2.74	2.77	-2.68	2.88	-2.61	2.88	-2.61

OK Print Save Help

C:\My Documents\Laminator3\Laminates\

Analysis Results

Material Strengths
****

Matl	Xt	Xc	Yt	Yc	S
1	29000.0	-26000.0	29000.0	-26000.0	11000.0

New shear strength is: 1.38 x 1000 /0.111 =12,432 psi

Load Vector Scale Factors for Ply Failure
(For Applied (+) and Reversed (-) Loads)
****

Layer	Max Stress (+)	Max Stress (-)	Tsai Hill (+)	Tsai Hill (-)	Hoffman (+)	Hoffman (-)	Tsai-Wu (+)	Tsai- (-)
1	1.38	-1.38	1.38	-1.38	1.38	-1.38	1.38	-1.3
2	2.35	-2.35	1.45	-1.40	1.43	-1.43	1.43	-1.4
3	1.38	-1.38	1.38	-1.38	1.38	-1.38	1.38	-1.3
---	-------	-------	-------	-------	-------	-------	-------	------
Min	1.38	-1.38	1.38	-1.38	1.38	-1.38	1.38	-1.3

OK Print Save Help

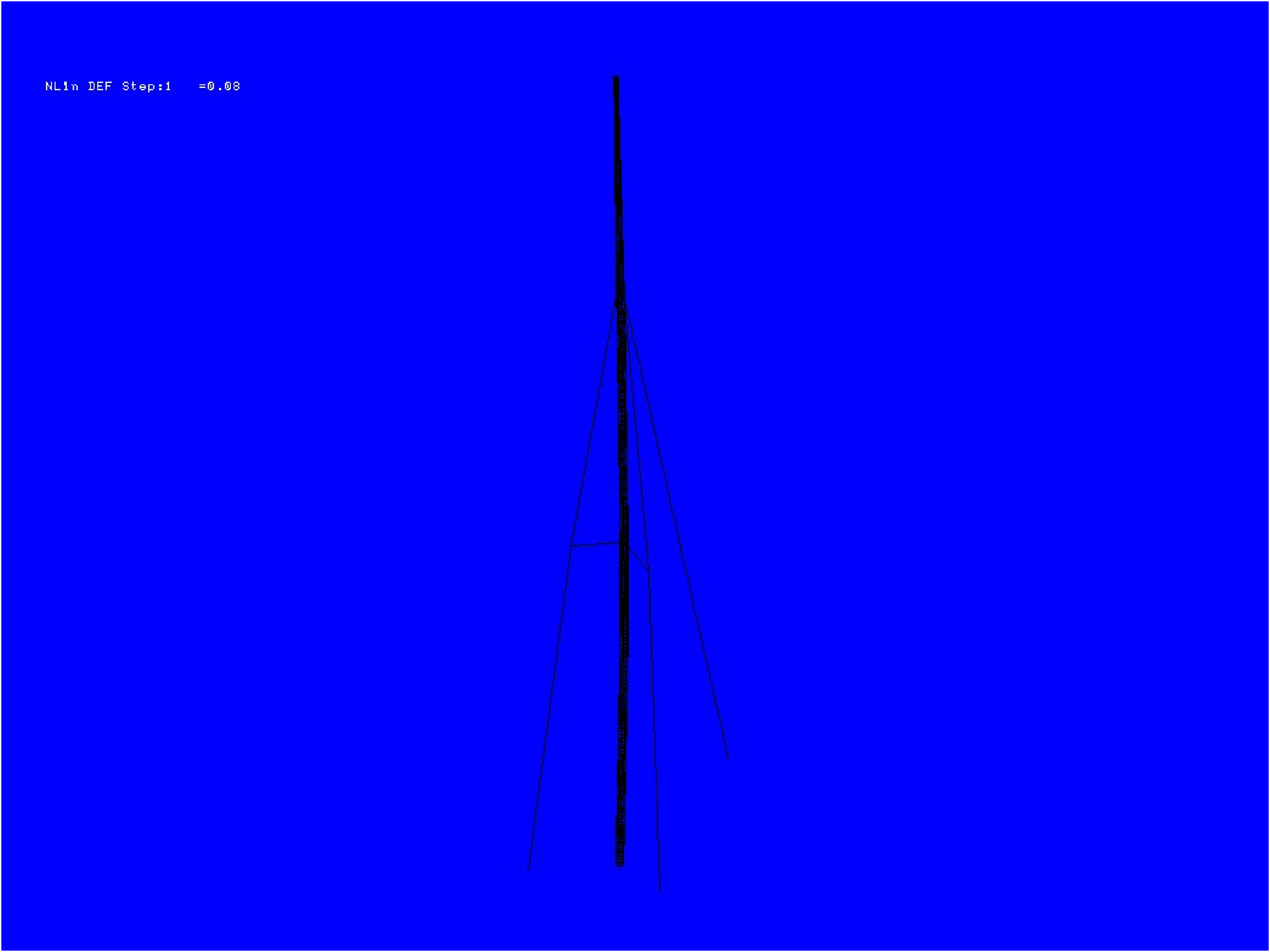
C:\My Documents\Laminator3\Laminates\

CLT/LPT

- Great way to find material properties for various combinations of mat, cloth, woven roving, uni, etc.
- Is used in composite elements in finite element analysis!

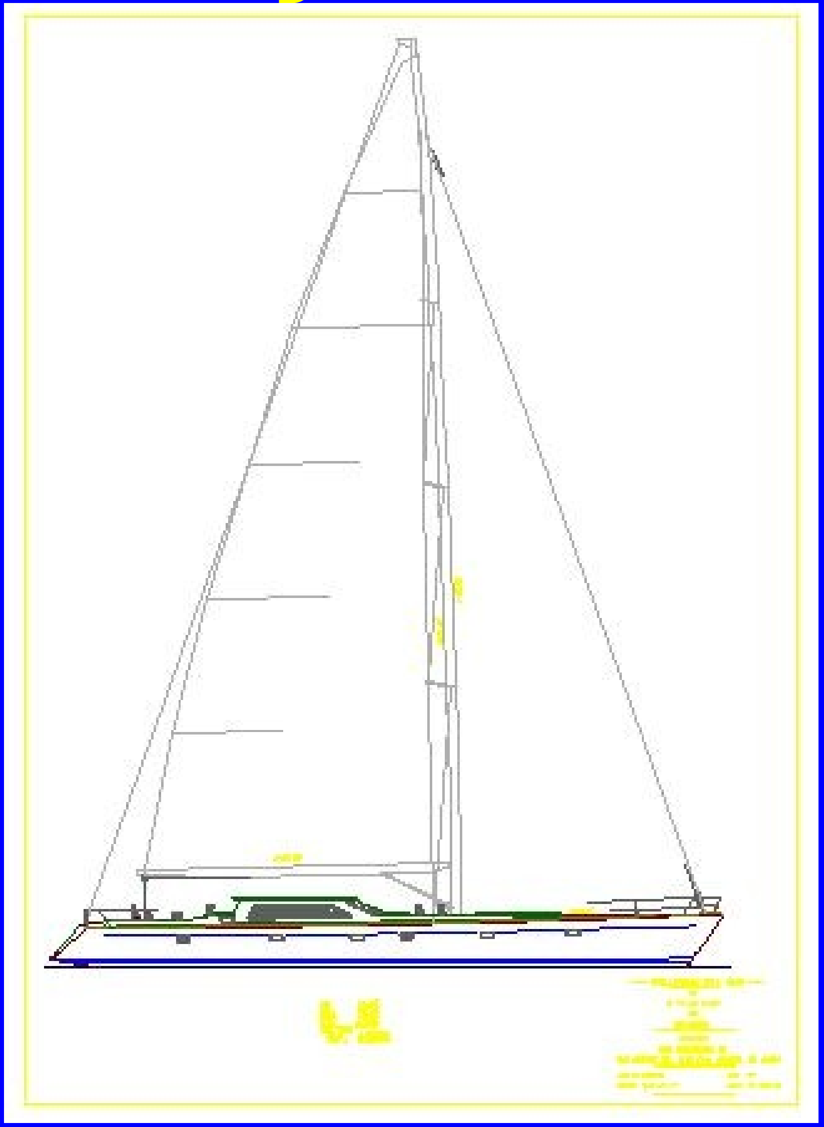
FEA

- Geometric modeler that internally generates equilibrium equations for force and displacement
- Steep learning curve, but great results
- Best for performance applications where stiffness or weight is critical


NL1n DEF Step:1 =0.08

A Case Study

- A 77-foot performance cruiser designed by Carl



FEA work

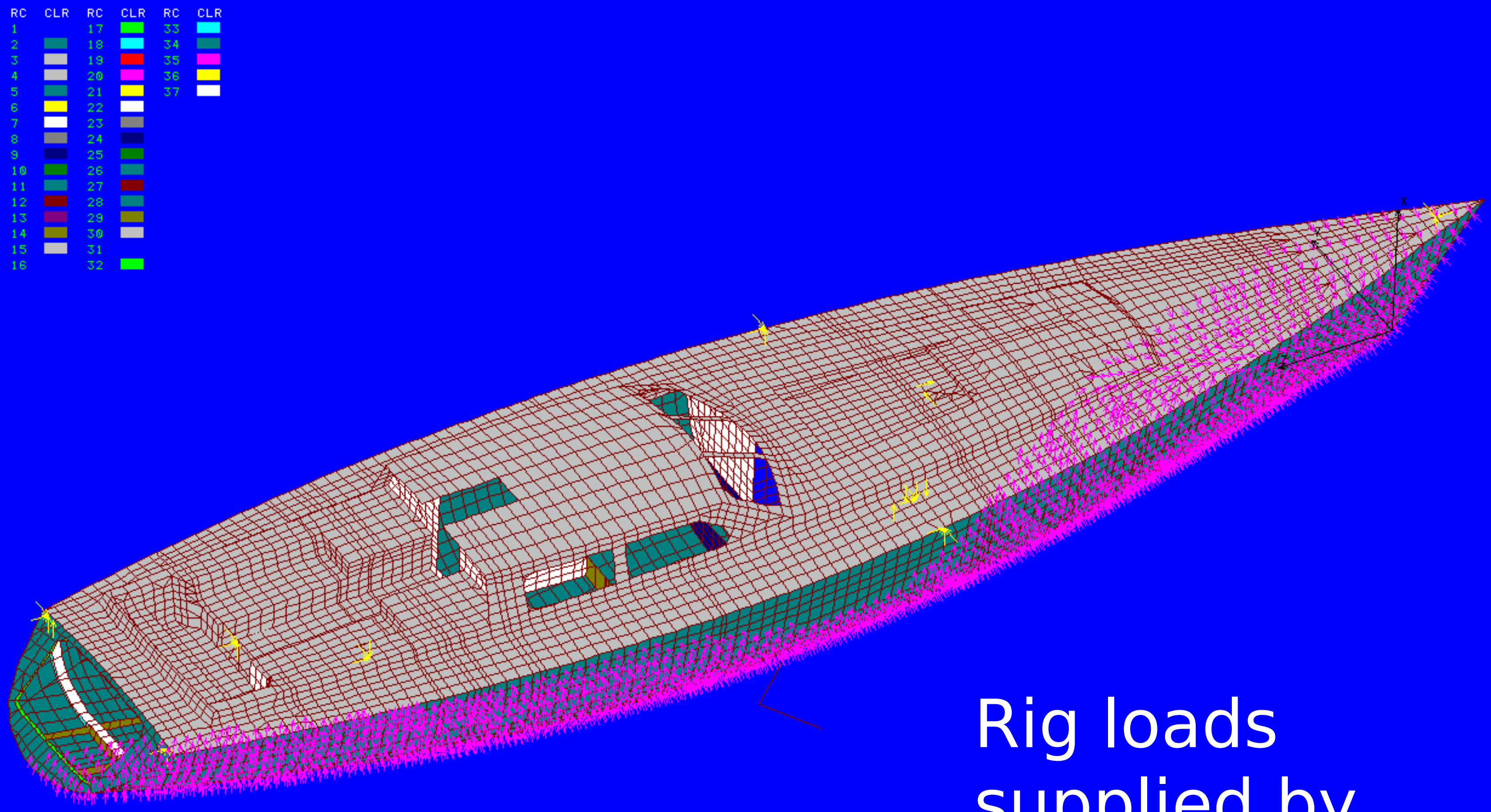
- Designer subcontracted out structural FEA design
- Designer provided dxf files for all geometries (hull, appendages)
- FEA consultants optimized and specified construction
- Designer did hull structure drawings
- Consultants did keel structure drawings and interfaced with keel and hull manufacturer to ease construction
- Consultants took 323 manhours, reduced structural weight 28%.

Design Limit Load Cases

- Upwind in heavy air, wave height equal to freeboard, wave length equal to boat length
- Slamming (from CFD consultant)
- Grounding (to ABS loads!)
- Lifting

Each load case drove the design of different parts of the boat.

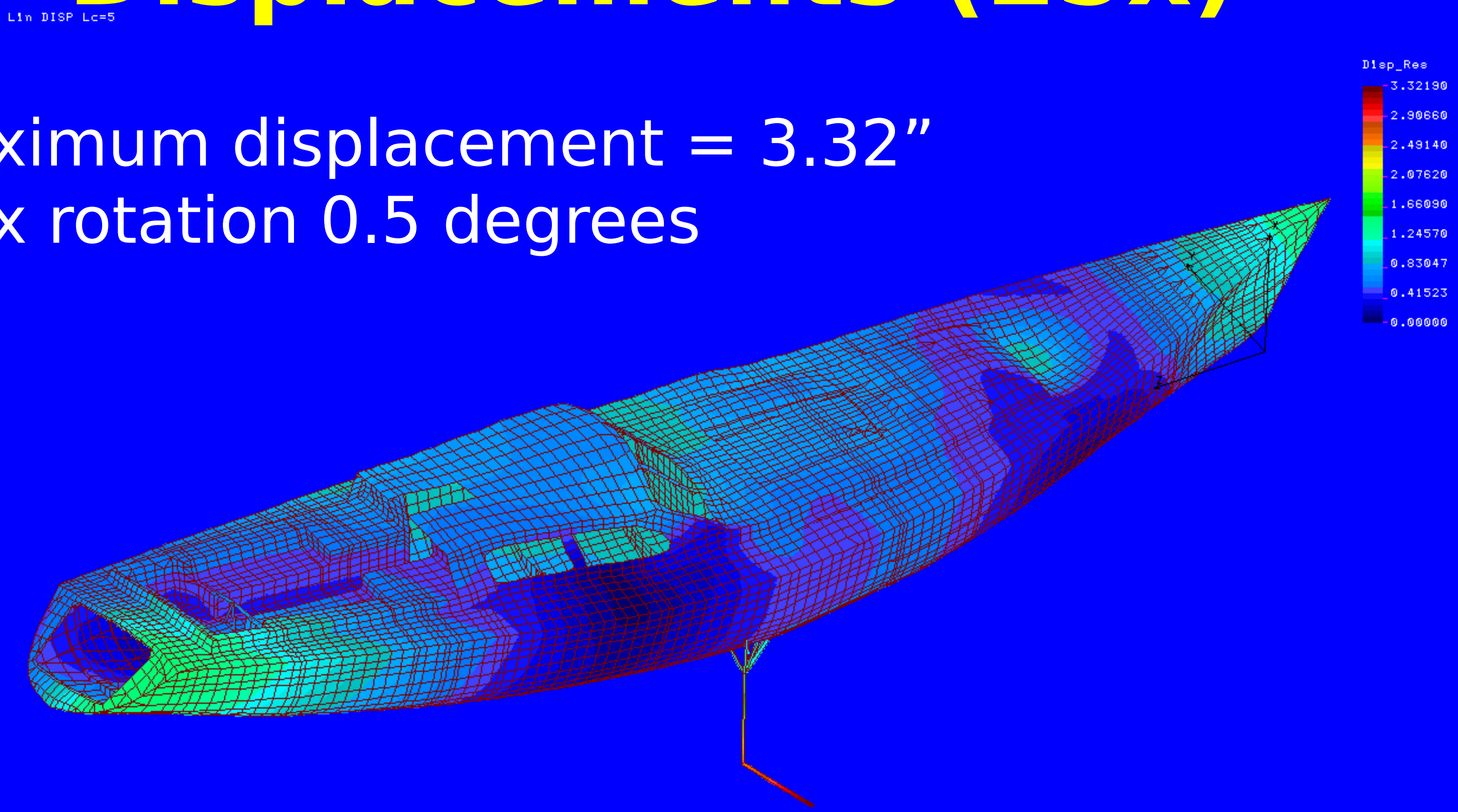
Upwind in 30 knots on port tack



Rig loads supplied by mast maker

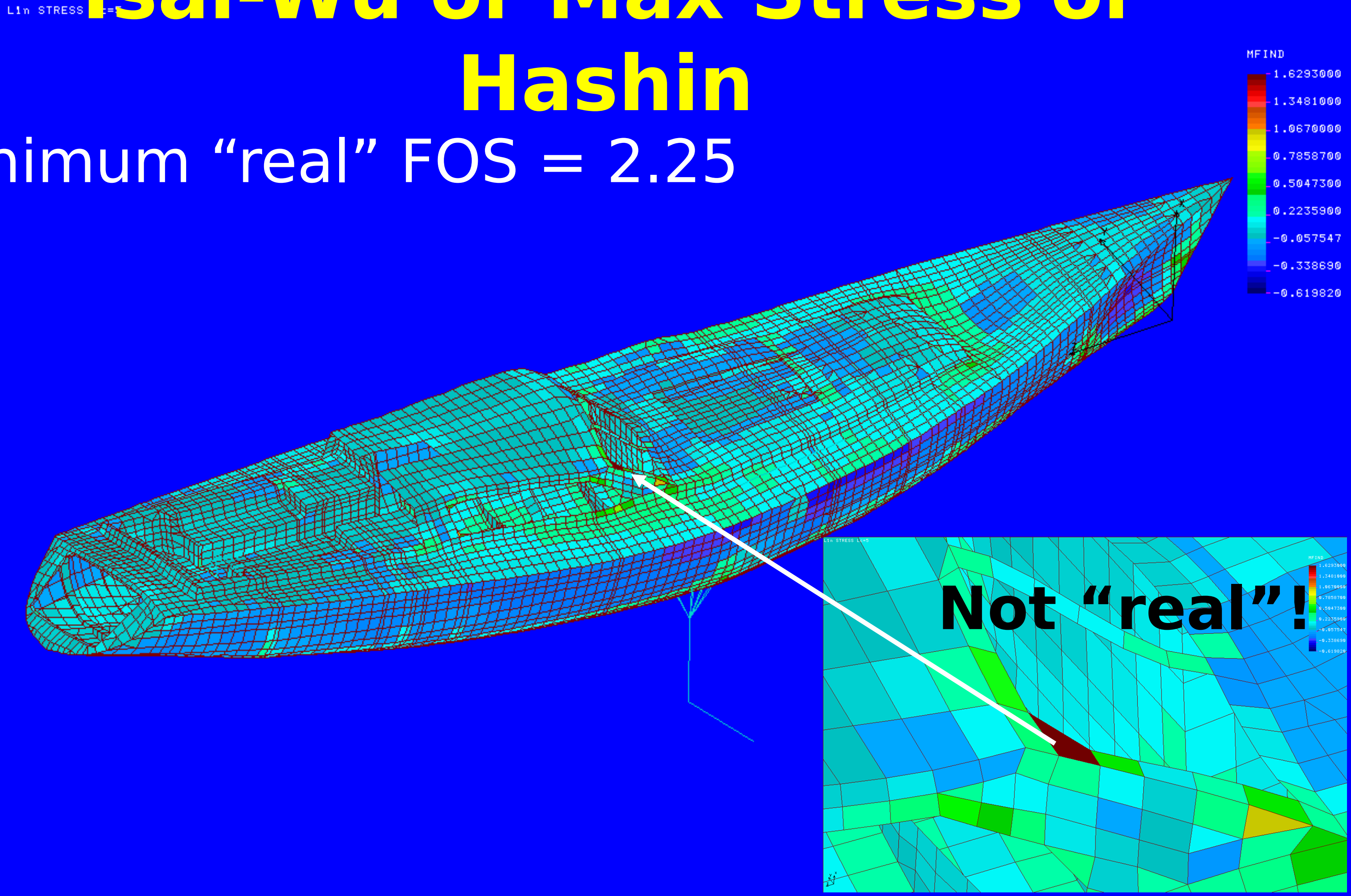
Displacements (25x)

Maximum displacement = 3.32”
Max rotation 0.5 degrees

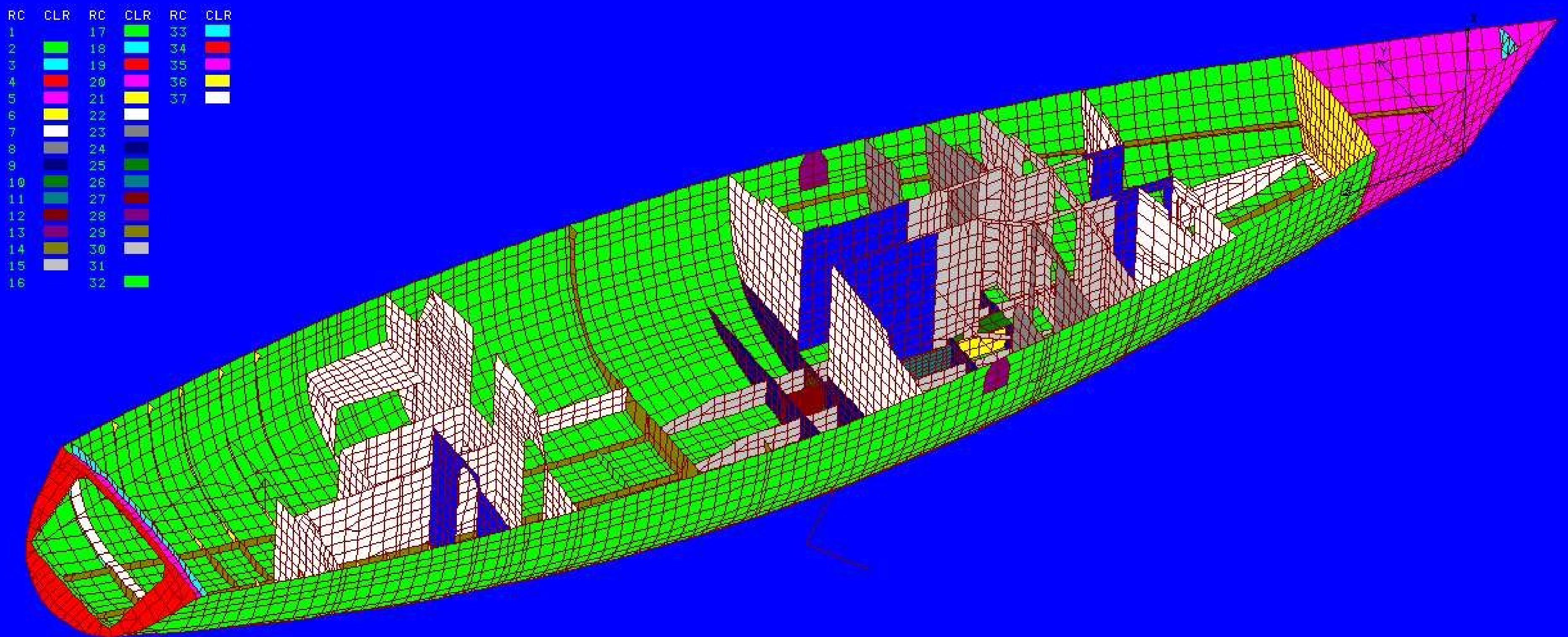


Factors of Safety
Tsai-Wu or Max Stress or Hashin

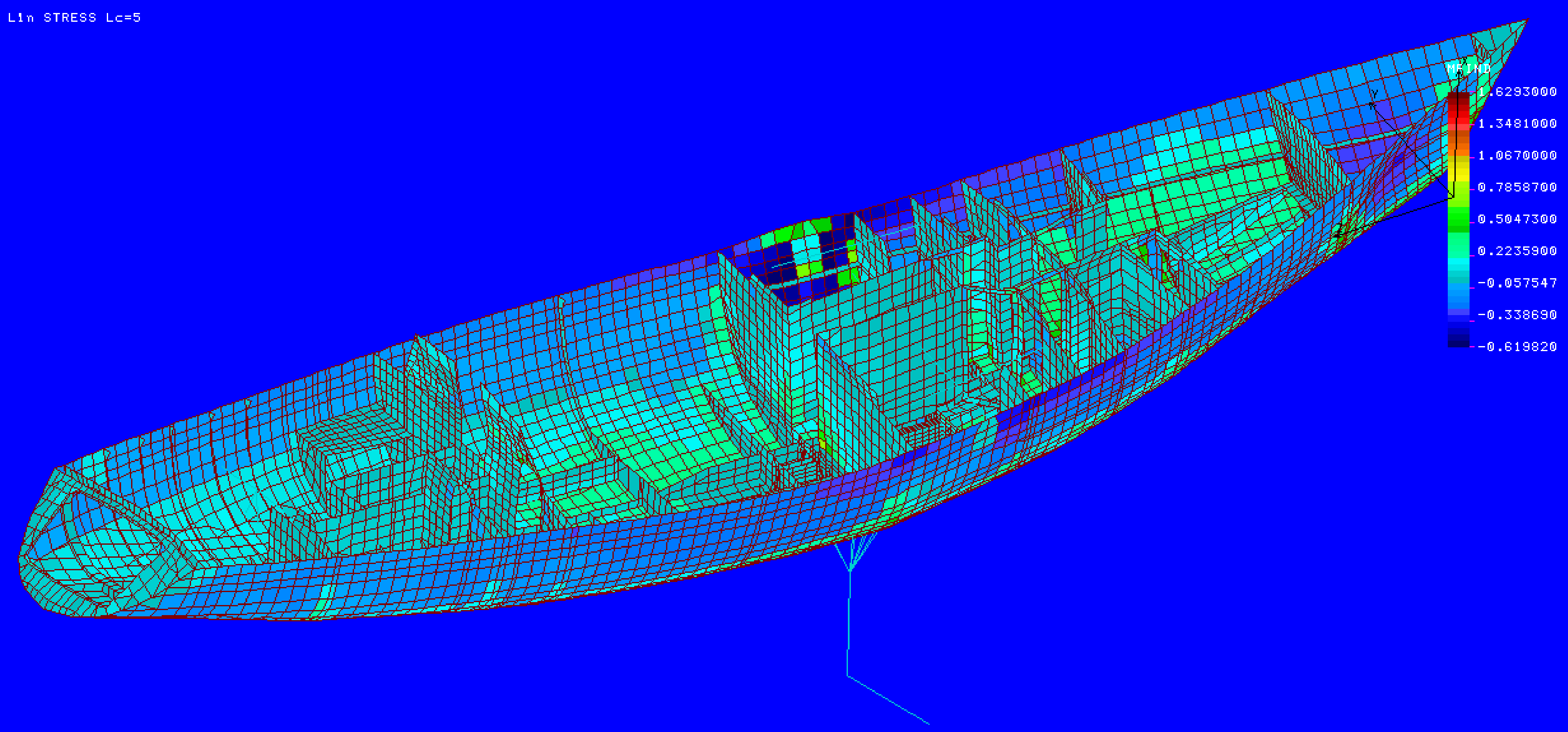
Minimum “real” FOS = 2.25



Interior

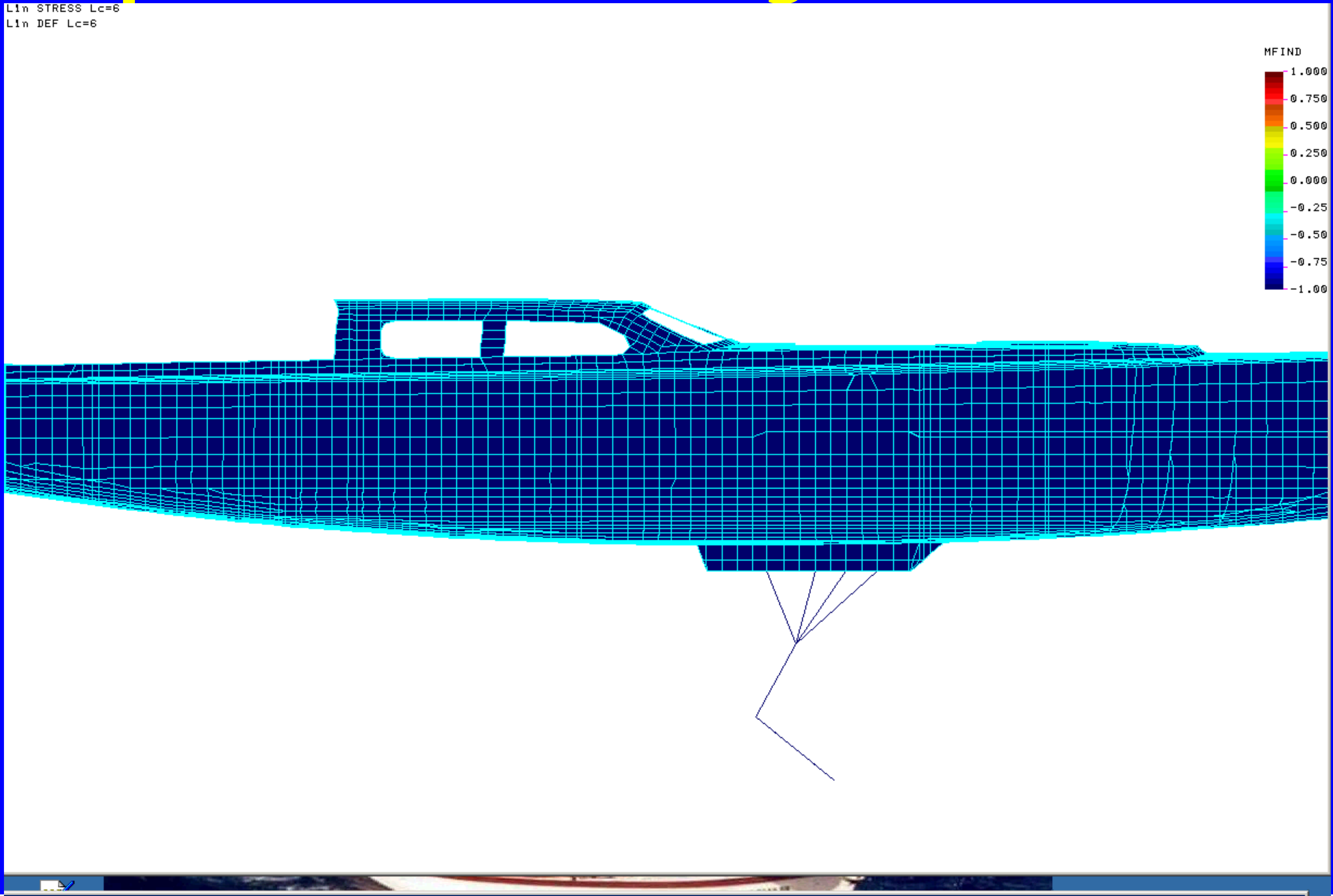

RC CLR RC CLR RC CLR
1 17 33
2 18 34
3 19 35
4 20 36
5 21 37
6 22
7 23
8 24
9 25
10 26
11 27
12 28
13 29
14 30
15 31
16 32

Interior FOS



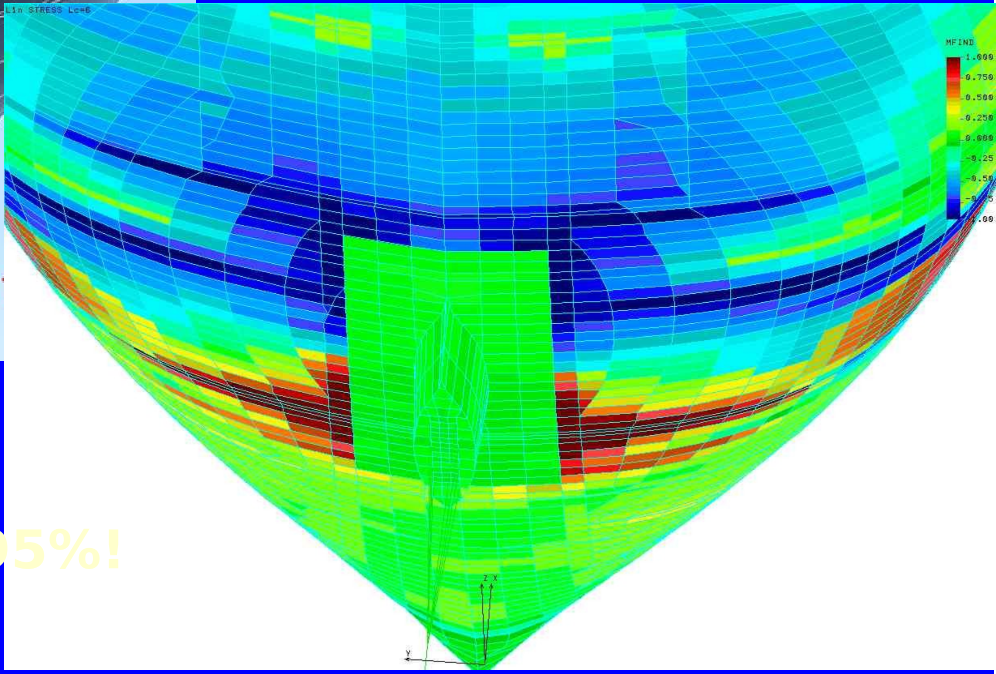
Session 206: Grounded!

Speed was 30% higher than ABS



Hull Damage

Outer Ply Factor of Safety



Correlation better than 95%!

FEA Suggestions

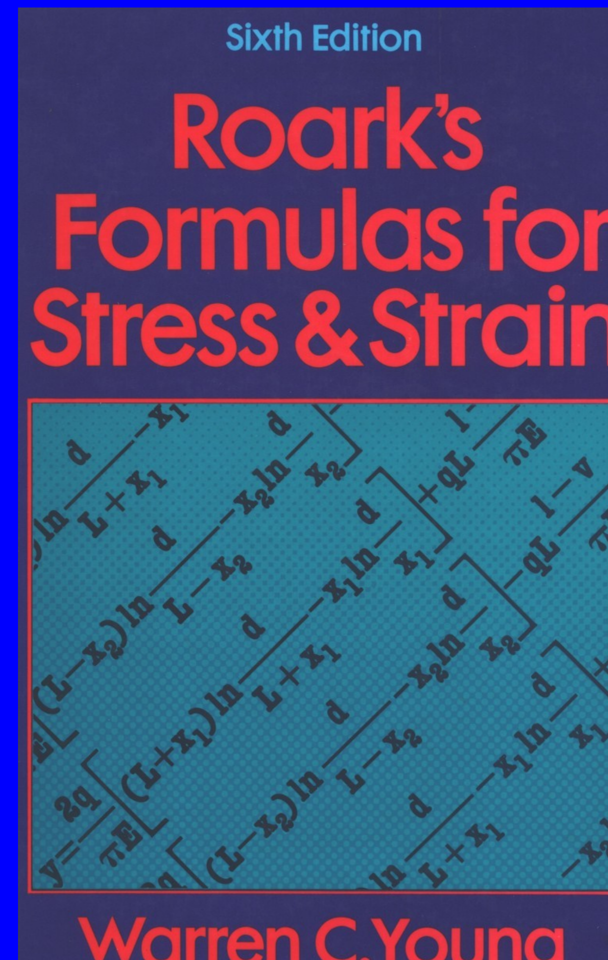
- A great tool to evaluate unintentional and planned modifications
- Efficient if performance is an issue or is a simple case (some projects less than 1 hour)
- Practice makes perfect
- Must use composite elements!

Final Thoughts

- Advanced marine composites design uses LPT and FEA more and more every day due to their demonstrated advantages
- Some engineering background is needed for the former, more for the latter!
- The Three Wright Brothers!
- Sleipner!

References

- Tsai
- Roark's



Contact Information

Paul H. Miller

Phmiller@usna.edu

410-293-6441

Google “Paul H. Miller” for my webpages